Spinning Targets for ICF

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Mix of the fuel with an imploding shell is a phenomenon that adversely affects pellet performance and eventually sets the limit for the energy yield of the fusion pellets. In the present paper, we describe a novel technique of suppressing the mix by spinning the pellet up prior to or in the course of its compression. We consider two approaches for spinning the pellets up [1]: i) using of the structured pellet surfaces which would produce an East-West asymmetry in the ablation rate and thereby create an ablation torque; ii) creation of the rotating layer deep inside the pellet by using impregnations which would cause an asymmetric reflection of the radially converging compression wave. Similar techniques could be used for spinning-up the imploding liners. It is important to note that, because of the angular momentum conservation, even relatively slow initial spin gives rise to a very fast rotation near the point of the maximum compression. The rotation should not necessarily be that of a solid body, the angular frequency may depend on both radius and the polar angle.

We present an analysis of the hydrodynamic problems associated with the interaction of the ablation torque and the underlying layers of the pellet. We come to a conclusion that, unless the pellet has an aspect ratio exceeding 20 or 30, elastic and viscous forces can not play a significant role in the transfer of the angular momentum from the surface to the deeper layers of the pellet. We evaluate the role of turbulent viscosity and conclude that it may be significant.

We study the interaction of a converging compression wave with the East-West asymmetric impregnations and find what level of the density variations is required to produce a sufficiently fast flow. It turns out that, for the typical conditions of current ICF experiments, the density variations of a few percent are sufficient. The shear flow that is produced in the layer where this structure is situated "smears out" initial non-uniformities so that their role as "seeds" for the Rayleigh-Taylor instability becomes insignificant. By a proper structuring of these non-uniformities, on can create the flow where not only the amplitude but also direction of the flow velocity would vary radially (very much like in magnetic shear).

We consider several specific examples of the effect of centrifugal force and shear flow on the Rayleigh-Taylor instability with a conclusion

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that, under certain circumstances, shear flow and centrifugal forces can have a strong stabilizing effect. One might think that shear flow would necessarily produce turbulent motions by itself but we present examples (based on the generalization of a so called Rayleigh theorem) when this is not the case. Solid-body rotation of the pellet as a whole could produce considerable deviations from the spherical symmetry but the stabilization of the fuel-shell interface requires creation of the rotation only near this interface thereby considerably reducing effect of rotation on the pellet symmetry.

We discuss possible ways of manufacturing the structured surfaces by a combination of etching and surface deposition. The structure could then remain on the pellet surface or be coated by the additional layers of the shell material. The latter approach allows one to create the structured layer at the arbitrary depth of the pellet. We speculate that, to create minor density non-uniformities insde the shell, one can use light interference technique. In this case, the shell (or some layers of it) should be made of photo-sensibilized materials.

Another group of applications of the ablative torque technique is related to possible improvement of the performance of the hohlraum in the indirect drive schemes. One of the problems that may surface in the upgraded versions of these schemes consists in a premature closure of the hohlraum windows by a plasma emerging from the inner walls of the hohlraum. By creating the East-West asymmetric structures on the inner surface of the hohlraum, one can make the plasma generated on this surface spin up around the hohlraum axis. The angular momentum conservation will then prevent the plasma from penetrating too close to the axis. For instance, if the initial rotation energy is as low as 0.1 of the thermal energy of the emerging plasma, the centifugal force will prevent the plasma from penetrating to the radii below, roughly speaking, 1/3 of the wall radius. We present relevant gas-dynamic solutions which allow one to quantitatively evaluate this effect.

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[1] D.E. Baldwin, D.D. Ryutov. Comments on Plasma Physics and Controlled Fusion, v.17, p.1, 1995.